Fair Energy Allocation for Collective Self-Consumption

Natalia Jorquera-Bravo[1,2], Sourour Elloumi[1,2], Safia Kedad-Sidhoum[2], Agnès Plateau[2]

[1] UMA, ENSTA Paris, Institut Polytechnique de Paris, France.
{natalia.jorquera, sourour.elloumi}@ensta-paris.fr

[2] CEDRIC, Conservatoire National des Arts et Métiers, France.
{safia.kedad_sidhoum,aplateau}@cnam.fr

Mots-clés : *Energy Management, Fair Allocation, Production Planning*

1 Introduction

In a time when renewable energy sources are gaining increasing prominence and communities seek to reduce their carbon footprint, collective self-consumption represents a fundamental transformation in the way individuals and communities access and use energy, offering a sustainable, economically viable, and environmentally friendly alternative to traditional energy distribution models [2]. Energy management under collective self-consumption empowers groups of individuals, neighborhoods, or even entire communities to unite and jointly harness, generate, and distribute locally produced renewable energy. It offers numerous advantages, including a reduced reliance on fossil fuels, lowered energy costs for participants, and decreased stress on the grid. Furthermore, this approach fosters a sense of ownership and environmental responsibility among participants, thereby strengthening the sense of community as they collaboratively embrace the energy transition [1, 3].

An essential aspect within self-consumption communities is the distribution of the generated energy, which becomes the responsibility of the legal entity managing the community. This entity must communicate the distribution of the electricity generated to the distribution system operator (DSO) [1]. For most of these communities, their operation can be divided into two major systems: a technical system and an economic system. The technical system must account for the actual distribution of energy, while the economic system considers the monetary distribution that occurs after the energy has been processed. Consequently, the financial balance of each participant depends on the distribution rules selected for the operation [4].

This work aims at incorporating fairness aspects for the allocation of green energy in collective self-consumption context.

2 Problem Statement

We study a microgrid composed of a set of J smart homes, a shared renewable distributed energy resource (DER) as a photovoltaic panel (PV), a common energy storage system (ESS) and a connection to the main power grid. Each house has an energy demand to satisfy over a discrete planning horizon. The demand can be satisfied either by using the DER, the battery, or by procuring electricity from the main power grid. Energy excess can be stored in the battery or sold back to the main grid. The battery has a charge and discharge efficiency, i.e. energy is lost when charging and discharging the battery. The objective is to find a supply plan that provides a fair allocation of renewable energy while minimizing the total cost of the microgrid. There is a manager, who may or may not be a physical person, in charge of managing the photovoltaic energy. This manager must report every 15 minutes the distribution of PV to the DSO, who is then in charge of issuing the bills for each user.

To address this problem, we propose a MILP model, where the daily cost is minimized by selecting the electricity output from the PV panel to each house as well as from the ESS, and the main grid. It also selects the electricity that each house stores in the ESS, and the amount of electricity that each house sells to the main grid. We study the complexity of this problem by proving its equivalence to a min cost flow problem.

Then, to address the fairness in the management of the shared DER, we introduce the *fair allocation rules*, where an allocation can be defined as the vector composed of the resource quantities allocated to each user. And, an allocation rule is the method used to calculate this allocation. We present four well-known allocation rules from the literature and we propose an implementation into our problem for each one. We also study the complexity of this problem considering fair allocation rules.

3 Numerical Experiments

We evaluate the obtained predictive models using real instances with up to 7 houses and a one-day time horizon with 15-minute time intervals. The data used for these instances are sourced from E4C[1] and pertains to a smart building located in France. We compare the results obtained for the allocation rules, and for the model without fairness. We analyze the autonomy of the microgrid, by studying the percentage of the demand that can be satisfied with the allocated PV energy and the battery. We also study the use of the PV energy that is allocated to each house, comparing it with the amount of electricity that is sold to the main grid. We highlight the advantages and disadvantages of each allocation rule and its impact on the building's electricity bill.

References

[1] Dorian Frieden, Andreas Tuerk, Ana Rita Antunes, Vasilakis Athanasios, Alexandros-Georgios Chronis, Stanislas d'Herbemont, Mislav Kirac, Rita Marouço, Camilla Neumann, Esteban Pastor Catalayud, Niccolò Primo, and Andrej Ferdo Gubina. Are we on the right track? collective self-consumption and energy communities in the european union. *Sustainability*, 13(22), 2021.

[2] Dorian Frieden, Andreas Tuerk, Camilla Neumann, S d'Herbemont, and Josh Roberts. Collective self-consumption and energy communities: Trends and challenges in the transposition of the eu framework. *COMPILE, Graz, Austria*, 2020.

[3] Vladimir Z. Gjorgievski, Snezana Cundeva, and George E. Georghiou. Social arrangements, technical designs and impacts of energy communities: A review. *Renewable Energy*, 169:1138–1156, 2021.

[4] Anthony Roy, Jean-Christophe Olivier, François Auger, Bruno Auvity, Salvy Bourguet, and Emmanuel Schaeffer. A comparison of energy allocation rules for a collective self-consumption operation in an industrial multi-energy microgrid. *Journal of Cleaner Production*, 389:136001, 2023.

[1] Interdisciplinary center Energy4Climate of Institut Polytechnique de Paris and École des Ponts ParisTech.